

Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

a HD1751

u 56

677 2

U.S. DEPT. OF AGRICULTURE
ECONOMICS, STATISTICS, AND COOPERATIVES SERVICE

ECONOMICS OF WATER QUALITY IN AGRICULTURE— A LITERATURE REVIEW

Clayton W. Ogg
Lee A. Christensen
Ralph E. Heimlich

U.S. Department of Agriculture
Economics, Statistics, and Cooperatives Service

ESCS-58

BIBLIOGRAPHIC DATA SHEET	1. Report No. ESCS-58	2.	3. Recipient's Accession No.
4. Title and Subtitle ECONOMICS OF WATER QUALITY IN AGRICULTURE---A LITERATURE REVIEW		5. Report Date July 1979	
		6.	
7. Author(s) Clayton W. Ogg, Lee A. Christensen, and Ralph E. Heimlich		8. Performing Organization Rept. No. ESCS-58	
9. Performing Organization Name and Address Natural Resource Economics Division Economics, Statistics, and Cooperatives Service U.S. Department of Agriculture Washington, D.C. 20250		10. Project/Task/Work Unit No.	
		11. Contract/Grant No.	
12. Sponsoring Organization Name and Address		13. Type of Report & Period Covered Final	
		14.	
15. Supplementary Notes			
16. Abstracts This review describes studies in several disciplines which contribute to understanding economic impacts of reducing nonpoint pollution. Cost studies reviewed deal with controlling soil erosion, nutrient losses, and pesticide losses. Other studies reviewed suggest where and how widely control practices may be needed. One area in need of research concerns the relationships between erosion reduction and the delivery of sediment and chemicals to streams. Research is also needed on the benefits of pollution reduction.			
17. Key Words and Document Analysis. 17a. Descriptors Economic analysis Erosion Expenses Pesticides Pollution Sedimentation Soil erosion Water pollution Water quality 17b. Identifiers/Open-Ended Terms Control practices Nonpoint pollution Nutrient losses Pesticide delivery 17c. COSATI Field/Group 02-C, 13-B			
18. Availability Statement Available from: NATIONAL TECHNICAL INFORMATION SERVICE, 5285 Port Royal Road, Springfield, Va. 22161		19. Security Class (This Report) UNCLASSIFIED 20. Security Class (This Page) UNCLASSIFIED	21. No. of Pages 22. Price

PREFACE

This review was done as background for ongoing research on the socioeconomic impacts of practices to reduce water pollution from agricultural sources. A wide range of studies from various disciplines are referenced, since economic studies must rely on physical production, biological and hydrologic relationships, as well as economic and social interactions. Because of the variety and number of studies, the authors do not claim to fully appreciate the relative importance of each. Some of the most significant works from the standpoint of a particular discipline may have been overlooked. Even so, the authors hope this review identifies some of the major issues and relationships and will prove useful to others in conducting economic analyses and developing information for policymakers.

CONTENTS

	<u>Page</u>
INTRODUCTION.....	1
LOCATING POLLUTION SOURCES.....	2
Discussion.....	2
Bibliography.....	6
ANALYZING CONTROL MEASURES AND THEIR COSTS.....	19
Discussion.....	19
Bibliography.....	21
POLLUTION DYNAMICS IN RURAL LAKES, STREAMS, AND ESTUARIES.....	25
Discussion.....	25
Bibliography.....	28
BENEFITS OF WATER QUALITY IMPROVEMENT.....	35
Discussion.....	35
Bibliography.....	36
OTHER BIBLIOGRAPHIES.....	39

Economics of Water Quality in Agriculture

– A Literature Review

Clayton W. Ogg, Lee A. Christensen, and Ralph E. Heimlich*

INTRODUCTION

Economists often rely on physical production relationships from engineers and physical scientists to formulate economic relationships for public decisionmakers. Incomplete knowledge of certain physical relationships can therefore limit economic analysis concerning management systems for reducing diffuse agricultural sources of pollution. Such nonpoint pollutants include pesticides and nutrients which are transformed in ways that are highly dependent on interacting influences of soils, weather, and hydrologic parameters, as well as farming practices. In turn, stream and lake characteristics affect the transport of sediment and other pollutants and the way these pollutants affect bodies of water. Finally, the public's perception of pollution damage is an important aspect of the social impact. Research on each of these problems is highly relevant to assessment of economic impacts of nonpoint pollution abatement.

In the past few years, scientists and engineers have produced a great many studies documenting pollution from farmland sources. Most of these estimate cropland-related contributions to measured problems in a particular reach of a stream or lake. Other studies develop information systems which relate measured water quality problems to specific crop practices with their varying impacts on water quality.

Studies identified in this report will assist in the assessment of the costs and benefits of cleaning rural lakes and streams. The principal purpose of this review is to identify some of the major issues influencing the solution of agricultural nonpoint pollution problems. In particular, the report emphasizes the relationship between technical and economic factors. It seeks to identify what is known about the economic impacts of alternatives for solving pollution problems from diverse agricultural sources, and to indicate the

*Ogg and Christensen are agricultural economists and Heimlich is an economist, all with ESCS.

limits of current knowledge. Areas which merit further effort by economists and scientists from other fields are also discussed. This review may be useful to researchers and water quality planners since it brings together several economic considerations critical to solving pollution problems.

The report first discusses publications which estimate local farm-related pollution. In some cases, authors compare local practices with hypothetically less polluting alternatives. These comparisons apply to a narrow range of soil or hydrologic conditions. This area of study primarily raises particular regional problems without attempting an indepth analysis of solution impacts.

There are, however, a number of modeling efforts which relate problems to specific practices on a full range of land conditions. Costs of various management practices are then estimated and compared with the associated biological benefits. Several erosion and sedimentation studies in particular develop important links between physical and economic relationships.

The effects of pollutants and their movement through streams, estuaries, and lakes are considered. References describe dynamics of typical stream delivery systems and impacts on different sizes and types of receiving waters. In some instances, recommended structural or biological solutions are discussed.

LOCATING POLLUTION SOURCES

Cost estimates for nonpoint pollution reduction usually call for inputs from several disciplines. Nutrient and pesticide studies reflect this diversity, providing only partial information for drawing economic implications. For instance, numerous studies have considered important nutrient management alternatives on a typical local soil. However, key economic questions of how these practices would affect potential problems and yields on other soil-slope combinations, or how widely they would be applied, are generally not addressed.

Discussion

In contrast, the studies of erosion reduction indicate that economic impacts are much more completely understood, partly because sediment models build on decades of work by natural scientists and engineers. These erosion studies make it possible to compare economic and environmental effects of crop management alternatives applied to an area's specific soil acreages.

Agricultural Chemicals

A large number of chemical studies attempt to prove the existence or absence of local agricultural pollution problems, either from stream sampling systems or from carefully controlled experiments on individual plots. Sometimes researchers were able to locate the source of a specific lake problem and identify a fairly simple solution to the nonpoint problem [a good example

is a study by the Minnesota Pollution Control Agency (44)]. 1/ In a few cases, authors found that local agriculture practices were relatively harmless in terms of nutrient and pesticide contributions, while others found nutrient problems that appeared virtually unsolvable (28, 35).

A number of efforts seek to identify the physical effects of nutrient management alternatives on a particular soil using experimental plots. That phosphorus losses can be reduced by methods of application is well documented by Timmons (73). Nitrogen losses are greatly affected by the timing of fertilizer applications (8, 38, 48).

Other studies emphasize the diverse levels of nutrient losses, which depend on the soil characteristics within each region. 2/ Gambrell, Gilliam, and Weed, for instance, find wide variations in nitrate loss between two important soils in the coastal plain of North Carolina (24).

Since experiments obviously cannot be repeated for every field situation, there have been efforts to identify parameters which determine pollution from nonpoint sources. Regression analyses by Omernik relating the most general agricultural variables such as cropland to total area ratios have identified strong relationships between the amount of agricultural land and each region's pollution from other than point sources (49). Such surveys and single modeling efforts are most useful in identifying large regions where agriculture is most likely to be affected by programs aimed at cleaning rural lakes and rivers.

There are projects underway to simulate specific field sources of pollution by developing watershed nutrient models. Nitrogen models pull together basic research data on the changes that nitrogen undergoes in the soil and in plant residues to predict the amount of nitrogen and nitrates reaching streams. These models include, for example, effects of soil wetness on denitrification (65), plant uptake under different concentrations (77), effects of temperature, and direction of nitrate movement between ground water and surface water (24). Early conceptual work by Bailey and others (94), and pesticide modeling by Crawford and Donigian laid the groundwork for the comprehensive agricultural runoff model by Donigian and Crawford (15, 17). Another comprehensive model relating several parameters is the ACTMO model developed by Frere, Onstad, and Holtan (22). 3/ Lack of parameters representing nutrient and pesticide pollution from soils of differing productivity limits applicability for economic analysis.

Of the major nutrient modeling efforts, a nitrate model developed by William Schaffer provides the most systematic basis for analyzing economic impacts of management alternatives (58). Yet this work is limited to a rather

1/ Underscored numbers in parentheses correspond with the references cited in the selected bibliography.

2/ Studies which emphasize drainage practices and drainage characteristics of soils are referenced on page 5.

3/ References in this section include many sources used by the large models. However, a number of equally important experiments, primarily of interest to specialists, are not included here.

narrow range of management alternatives on one New York watershed. Models have not yet been constructed with the capacity of accurately analyzing the interaction of management practices and soil-hydrologic relationships for any representative area. Until these relationships are established for soils of varying productivity, economic effects of nutrient reductions cannot be rigorously estimated.

Enrichment Ratios

For most soils, a large portion of the total phosphorus in runoff is adsorbed by soil and carried to streams with the eroding particles. One approach to analyzing phosphorus control alternatives is to estimate how much phosphorus is delivered with the sediment. This is the approach taken by Jacobs and Schaffer and others (30, 58). However, nutrients are primarily available for algae growth in their dissolved state; even for phosphorus, areas which produce large amounts of nutrient adhering to sediment may not be the only ones which contribute to algae growth (53, p. 323). Reduced tillage management alternatives recommended for sediment problems also alter nutrient enrichment ratios as the dissolved phosphorus losses rapidly increase (34, 55, 59).

More sophisticated enrichment studies which take into account the adsorptive capacities of soils under different practices affecting sediment concentrations in runoff are needed. Otherwise, concentration on erosion reduction may divert efforts from other potential management practices designed specifically for agricultural chemical problems. These include such practices as controls on the amount of pesticides or nitrogen fertilizer or manure applied, the method of phosphorus application, or the timing of nitrogen application (55, p. 295). Karr and Schlosser argue that creating buffer zones between crop locations and the streams deals with nutrient problems in several ways and provides for wildlife and environmental needs as well (31).

The limited nature of the economic literature dealing with nutrient and pesticide problems does not necessarily indicate that solutions are going to be particularly difficult or expensive. If nutrient use is severely reduced, the conventional wisdom is that costs will be considerable (32, 71). Yet preliminary results indicate that there are a number of important soil situations where proper fertilizer placement, combined with modern reduced tillage methods, can significantly reduce phosphorus loss from most well-drained soils without large cost (36). 4/ Likewise, soil loss management, combined with proper timing and application rates, will substantially reduce nitrogen loss (63), possibly at very low cost. Bouldin and others at Cornell even argue that summer sidedress applications of nitrogen can achieve actual profit increases while reducing nitrogen available for runoff by over 50 percent, as compared to fall plowdown (8, 38). This is supported by a Missouri study by Whitaker and associates (80). Although rigorous cost information is scarce for many soils and for exacting

4/ Again, it should be emphasized that there are heavy or wet soils where no-till does not produce as well, plus many unknown difficulties such as with man-
agement, especially for small farmers.

environmental objectives, real gains may be achieved in the next few years if available fertilizer management practices and appropriate reduced tillage technologies are adopted.

Pesticide Monitoring

Analogous to the studies for nutrients are three types of pesticide monitoring studies. The simplest of these are purely descriptive studies which record pesticide residues found in water or alluvial sediments in a particular area (96). More generally applicable are studies which derive some statistical relationships between pesticide concentrations in runoff and associated phenomena such as sediment yields (94, 98, 99). Because of the toxic effects of pesticides and their tendency to accumulate in organic tissues, a third kind of study examines these effects on particular species (95) or for all organisms in a certain level of the food chain (97).

Pollutants from Other Nonpoint Sources

Surface runoff of soil, pesticides, and commercial fertilizer nutrients is only part of the problem in many areas of the Northeast. Several studies emphasize the importance of ground water pollution, manure application, tile drainage, surface drainage of former swamps, and irrigation return flows. Management alternatives for surface runoff often do not apply, and new techniques of analysis have been developed for each of these problems. For instance, key economic variables for manure handling are storage costs and costs of soil incorporation (115). Construction of drainage outlets themselves becomes an issue for surface drainage, since drainage may open reservoirs of nutrients (125, 128). Water management is a variable unique to irrigated sources (104).

Sediment Sources

Economic analysis of erosion and sediment control has developed a standard for measuring the progress of other nonpoint pollution analysis. Wischmeier and Smith's Universal Soil Loss Equation (USLE) is now widely used (in revised form) as a common basis for identifying pollution problems for farm conservation planning (142, 145), and has been adapted for economic analysis. Based on initial fallow soil loss condition, factors for rainfall, soil erodability, slope, slope length, conservation practices, tillage, and crop rotation provide soil loss estimates for a typical year. If used correctly, the USLE can be used for regional studies as it is for individual fields (143). By relating soil productivity to aggregated soil loss for selected groups of soils, the economic effects of rather detailed soil-specific conservation recommendations are established. Since the USLE is geared to describing typical yearly events, it is particularly well suited to analyzing the broad implications of management strategies. Much of the economic analysis of nonpoint pollution has made use of the USLE.

The major weakness of using the USLE in pollution studies is that estimates are for soil movement on the field and do not indicate how much of the eroded particles reach streams. Techniques for indicating delivery of sediments to streams are far less advanced than those for estimating erosion. A method by Roehl, which is used widely (138), accounts neither for variation in delivery rates within a watershed nor for the effects conservation practices may have on delivery rates (139). The USLE, however, has been successfully adapted to provide estimates of delivered sediments, using an equation that requires estimates or measurement of total runoff and peak flows (141).

Bibliography

Agricultural Chemicals

- (1) Alexander, M.
"Nitrification," Soil Nitrogen. Ed. W. V. Bartholomew and F. E. Clark. Agron. Monograph No. 10, Madison: American Society of Agronomists, pp. 307-343, 1965.
- (2) Bailey, G. W.
Role of Soils and Sediment in Water Pollution Control. U.S. Environmental Protection Agency, Southeast Water Lab, Athens, Ga., March 1968.
- (3) Baker, D. B. and J. W. Kramer.
Phosphorus Sources and Transport in an Agricultural River Basin of Lake Erie. Proceedings 16th Conf. Great Lakes Res., pp. 858-871, 1973.
- (4) Bartholomew, W. V.
"Mineralization and Immobilization of Nitrogen in the Decomposition of Plant and Animal Residues," Soil Nitrogen. Ed. F. E. Clark. Agron. Monograph No. 10, Madison: American Society of Agronomists, pp. 285-306, 1965.
- (5) Bates, T. E. and S. L. Tisdale.
"The Movement of Nitrate-Nitrogen through Columns of Coarse-Textured Material," Soil Science Society of America Proceedings. Vol. 21, 1957.
- (6) Baumann, E. R., J. G. Deboer, and C. S. Oulman.
"Five Year Study of Des Moines River Water Quality," Agricultural and Urban Considerations in Irrigation and Drainage; Selected Papers from the Irrigation and Drainage Division Speciality Conference. Fort Collins, Colo., Apr. 22-24, pp. 711-727, 1974.
- (7) Betson, R. P. and W. M. McMaster.
"Nonpoint Source Mineral Water Quality Model," Journal of the Water Pollution Control Federation. Knoxville: Tennessee Valley Authority, Hydraulic Data Branch. Vol. 47(10):2,461-2,473, 1975.

- (8) Bouldin, D. R., W. S. Reid, and D. J. Lathwell.
"Fertilizer Practices Which Minimize Nutrient Loss," Agricultural Wastes: Principles and Guidelines for Practical Solutions. Proceedings of Cornell Univ. Conf., Agr. Waste Management, Syracuse, N.Y., 1971.
- (9) Bradford, Robert R.
Nitrogen and Phosphorus Losses from Agronomy Plots in North Alabama. U.S. Environmental Protection Agency, Vol. 660/2-74-033, April 1974.
- (10) Broadbent, F. E. and F. Clark.
"Denitrification," Soil Nitrogen. Ed. W. V. Bartholomew and F. E. Clark. Agron. Monograph No. 10, Madison: American Society of Agronomists, pp. 394-395, 1965.
- (11) Burwell, R. E., G. E. Schuman, K. E. Saxton, and H. G. Heinemann.
"Nitrogen in Subsurface Discharge from Agricultural Watersheds," Journal of Environmental Quality. Vol. 5:325-329, 1976.
- (12) Burwell, R. E., D. R. Timmons, and R. F. Holt.
"Nutrient Transport in Surface Runoff as Influenced by Soil Cover and Seasonal Periods," Soil Science Society of America Proceedings. Vol. 39: 523-528, 1975.
- (13) Chichester, F. W.
"Effects of Increased Fertilizer Rates on Nitrogen Content of Runoff and Percolate from Monolith Lysimeters," Journal of Environmental Quality. Vol. 6:211-217, 1977.
- (14) _____.
"Impact of Fertilizer Use and Crop Management on Nitrogen Content of Subsurface Water Draining from Upland Agricultural Watersheds," Journal of Environmental Quality. Vol. 5: 413-416, 1976.
- (15) Crawford, Norman H. and Anthony S. Donigian, Jr.
"Pesticide Transport and Runoff Models for Agricultural Lands." U.S. Environmental Protection Agency, Vol. 660/2-74-013, December 1973.
- (16) Donigian, Anthony S., Jr., Douglas C. Beyerlein, Harley H. Davis, Jr., and Norman H. Crawford.
Agricultural Runoff Management (ARM) Model, Version II: Refinement and Testing. U.S. Environmental Protection Agency, Vol. 600/3-77-098, August 1977.
- (17) Donigian, Anthony S. and Norman H. Crawford.
Modeling Nonpoint Pollution from the Land Surface. U.S. Environmental Protection Agency, Vol. 600/3-76-083, July 1976.
- (18) _____.
Modeling Pesticides and Nutrients on Agricultural Lands. Res. Grant No. R803116-01-0, U.S. Environmental Protection Agency, Vol. 600/2-76-043, February 1976.

- (19) _____.
Simulation of Nutrient Loadings in Surface Runoff with the NPS Model.
U.S. Environmental Protection Agency, Vol. 600/3-77-065, June 1977.
- (20) Dutt, G. R., M. T. Shaffer, and W. J. Moore.
Computer Simulation Model of Dynamic Bio-Physiochemical Processes in Soils. Univ. of Arizona, Dept. of Soils, Water, and Engineering and the Tucson, Ariz. Agr. Expt. Stn., Technical Bull. 196, 1972.
- (21) Enfield, C. G., and D. C. Shew.
"Comparison of Two Predictive Nonequilibrium One-Dimensional Models for Phosphorus Sorption and Movement through Homogeneous Soils," Journal of Environmental Quality. Vol. 4(2):198-202, 1975.
- (22) Frere, M. H., C. A. Onstad, and H. N. Holtan.
ACTMO, an Agricultural Chemical Transport Model. U.S. Dept. Agr., Agr. Res. Serv., Hyattsville, Md. ARS-H-3, 1975.
- (23) Fried, M., C. E. Hagen, J. F. Saiz del Rio, and J. E. Leggett.
"Kinetics of Phosphate Uptake in the Soil-Plant System," Soil Science. Vol. 84(6):427-437, 1957.
- (24) Gambrell, R. P., J. W. Gilliam, and S. B. Weed.
Contribution of Fertilizers to the Pollution of Waters in the North Carolina Coastal Plain. North Carolina Water Resources Res. Institute, Interim Report, 1972.
- (25) Grimsrud, G. P., E. J. Finnemore, and H. J. Owen.
Evaluation of Water Quality Models: A Management Guide for Planners. U.S. Environmental Protection Agency, Vol. 600/5-76-004, July 1976.
- (26) Hagin, J. and A. Amberger.
Contribution of Fertilizers and Manures to the N- and P-Load of Waters, A Computer Simulation. Report submitted to Deutsche Forschungs Gemeinschaft, 1974.
- (27) Hammer, M. J. and G. I. Hergenrader.
"Eutrophication of Small Reservoirs in Eastern Nebraska," Transactions of the Nebraska Academy of Sciences. Vol. 2:70-80, 1973.
- (28) Harms, L. L.
"Agricultural Runoff Pollutes Surface Waters, Part I," Water and Sewage Works. Vol. 122(10):84-85, 1975.
- (29) _____
"Bacteriological Quality of Surface Runoff from Agricultural Land, Part II," Water and Sewage Works. Vol. 122(11):71-73, 1975.
- (30) Jacobs, J. J.
Controlling Sediment and Nutrient Losses from Agricultural Land. Cornell Agr. Econ. Staff Paper No. 72-20, September 1972.

- (31) Karr, James P. and Isaac Schlosser.
"Water Resources and the Land-Water Interface," Science. Vol. 201:229-234, 1978.
- (32) Kasal, James.
Tradeoffs Between Farm Income and Selected Environmental Indicators: A Case Study of Soil Loss, Fertilizer, and Land Use Constraints. U.S. Dept. Agr., Econ. Res. Serv., Bull. No. 1550, 1976.
- (33) Keeney, D. R. and L. M. Walsh.
Sources and Fate of 'Available' Nitrogen in Rural Ecosystems. Proceedings of Conf. on Farm Animal Wastes, Nitrates and Phosphates in Rural Wisconsin Ecosystems, Madison, Green Bay, and Eau Claire, Wisc., pp. 22-40, Feb. 1-5, 1971.
- (34) Kelley, H. W.
"Conservation Tillage Hazards Ahead?" Soil Conservation. pp. 8-11 January 1977.
- (35) Kilkus, S. P., J. D. LaPerriere, and R. W. Bachmann.
"Nutrients and Algae in Some Central Iowa Streams," Journal of the Water Pollution Control Federation. Vol. 47(7):1,870-1,879, 1975.
- (36) Klausner, S. D., P. J. Zwerman, and D. F. Ellis.
"Surface Runoff Losses of Soluble Nitrogen and Phosphorus under Two Systems of Soil Management," Journal of Environmental Quality. Vol. 3:42-46, 1974.
- (37) Larsen, S.
"Soil Phosphorus," Advanced Agronomy. Vol. 19:151-210, 1967.
- (38) Lathwell, D. J., D. R. Bouldin, and W. S. Reid.
"Effects of Nitrogen Fertilizer Applications on Agriculture," reprint from Relationship of Agriculture to Soil and Water Pollution. Proceedings of Cornell Univ. Conf., Agr. Waste Management, Syracuse, N.Y., pp. 134-146, 1971.
- (39) Loehr, R. C.
"Characteristics and Comparative Magnitude of Non-Point Sources," Journal of the Water Pollution Control Federation. Vol. 56(8):1,849-1,872, 1974.
- (40) McBean, E. A. and J. E. Gorrie.
"Non-Point Source Contributions to Water Quality Problems," Water Pollution Research Canada. Proceedings of the 10th Canadian Symposium, pp. 142-150, 1975.
- (41) McElroy, A. D., S. Y. Chiu, J. W. Bebgren, A. Aleti, and F. W. Bennett.
Loading Function for Assessment of Water Pollution from Nonpoint Sources. U.S. Environmental Protection Agency, Vol. 600/2-76-151, May 1976.

- (42) McLaren, A. D.
"Temporal and Vectorial Reactions of Nitrogen in Soil: A Review,"
Canadian Journal of Soil Science. Vol. 50(2):97-109, 1970.
- (43) Mehran, M. and K. K. Tanji.
"Computer Modeling of Nitrogen Transformations in Soils," Journal of
Environmental Quality. Vol. 3(4):391-395, 1974.
- (44) Minnesota Pollution Control Agency.
Report on the Investigation of Water Quality of Christmas Lake Water-
shed. Division of Water Quality Report, January 1975.
- (45) Mortland, M. M. and A. R. Wolcott.
"Sorption of Inorganic Nitrogen Compounds by Soil Materials," Soil
Nitrogen. Agron. Monograph No. 10, pp. 150-197. Madison: American Soci-
ety of Agronomists, 1965.
- (46) Nicholson, H. P.
"The Needs for Water Quality Models on Agricultural Watersheds," Journal
of Environmental Quality. Vol. 4(1):23-33, 1975.
- (47) Oddson, J. K., L. Letey, and L. V. Weeks.
"Predicted Distribution of Organic Chemicals in Solution and Absorbed as
a Function of Position and Time for Various Chemicals and Soil Proper-
ties," Soil Science Society of America Proceedings. Vol. 31:412-417,
1970.
- (48) Olson, R. A., A. F. Dreier, C. Thompson, K. Frank, and P. H. Grabowski.
Using Fertilizer Effectively on Grain Crops. Nebraska Agr. Expt. Stn.
Bull. SB 479, 1964.
- (49) Omernik, J. M.
Nonpoint Source - Stream Nutrient Level Relationships: A Nationwide
Study. U.S. Environmental Protection Agency, Vol. 600/3-77-105, Septem-
ber 1977.
- (50) _____.
The Influence of Land Use on Stream Nutrient Levels. U.S. Environmental
Protection Agency, Vol. 600/3-76-014, January 1976.
- (51) Pisano, M. A.
"Nonpoint Sources of Pollution: A Federal Perspective," Journal of the
Environmental Engineering Division. Vol. 102(EE3), proceedings paper
12211, pp. 555-565, 1976.
- (52) Porcella, D. B. (ed.).
Comprehensive Management of Phosphorus Water Pollution. Utah State Univ.,
prepared for Off. Res. and Dev., U.S. Environmental Protection Agency,
Vol. 600/5-74-010, February 1974.
- (53) Porter, K. S. (ed.).
Nitrogen and Phosphorus: Food Production, Waste, and the Environment.
Ann Arbor, Mich.: Ann Arbor Science, 1975.

- (54) Roehl, J. W.
Sediment Source Areas, Delivery Ratios, and Influencing Morphological Factors. J.A.S.H. Commission on Land Erosion, Publication No. 59, 1962.
- (55) Romkens, M. J. M., D. W. Nelson, and J. V. Mannering.
"Nitrogen and Phosphorus Composition of Surface Runoff as Affected by Tillage Method," Journal of Environmental Quality. Vol. 2:292-295, 1973.
- (56) Romkens, M. J. M. and D. W. Nelson.
"Phosphorus Relationships in Runoff from Fertilized Soils," Journal of Environmental Quality. Vol. 3:10-13, 1974.
- (57) Sawyer, C. N. and P. L. McCarty.
Chemistry for Sanitary Engineers, 2nd ed. New York: McGraw-Hill Book Co., 1967.
- (58) Schaffer, William H., Jr.
An Economic Analysis of Nitrogen, Phosphorus and Soil Loss from Agricultural Production Affecting Water Quality in a Small New York Watershed. Ph.D. thesis, Cornell Univ., June 1974.
- (59) Schneider, Robert R.
"Planning Diffuse Pollution Control: An Analytical Framework," Water Resources Bulletin. Vol. 14:322-336, 1978.
- (60) Smith, C. N. and G. W. Bailey.
Transport of Agricultural Chemicals from Small Upland Piedmont Watersheds. U.S. Environmental Protection Agency, Vol. 600/3-78-056, 1978.
- (61) Soil Conservation Society of America.
Conservation Tillage. Proceedings of a National Conf., 1973.
- (62) Sonzogni, W. and G. F. Lee.
"Phosphorus Sources for the Lower Madison Lakes," Wisconsin Academy of Sciences, Arts and Letters. Vol. 63:162-175.
- (63) Stanford, G.
"Rationale for Optimum Nitrogen Fertilization in Corn Production," Journal of Environmental Quality. Vol. 2:159-166, 1973.
- (64) _____, C. B. England and A. W. Taylor.
Fertilizer Use and Water Quality. U.S. Dept. Agr., Agr. Res. Serv., 41-168, 1970.
- (65) Stanford, G. and E. Epstein.
"Nitrogen Mineralization--Water Relations in Soil," Soil Science Society of America Proceedings. Vol. 38:103-107, 1974.
- (66) Stanford, G., M. H. Frere, and D. E. Schwaninger.
"Temperature Coefficient of Soil Nitrogen Mineralization," Soil Science Society of America Proceedings. Vol. 115:321-323, 1973.

- (67) Stanford, G. and S. J. Smith.
"Nitrogen Mineralization Potential in Soil," Soil Science Society of America Proceedings. Vol. 36:465-472, 1972.
- (68) Stanford, G., R. A. Vander Pol, and S. Dzienia.
"Denitrification Rates in Relation to Total Extractable Soil Carbon," Soil Science Society of America Proceedings. Vol. 39:284-289, 1975.
- (69) _____.
"Effect of Temperature on Denitrification Rate in Soils," Soil Science Society of America Proceedings. Vol. 39(5):867-875, 1975.
- (70) Subbarao, Y. V. and R. Ellis, Jr.
Determination of Kinetics of Phosphorus Mineralization in Soils under Oxidizing Conditions. U.S. Environmental Protection Agency, Vol. 600/2-77-180, August 1977.
- (71) Taylor, C. R. and K. K. Frohberg.
"The Welfare Effects of Erosion Controls, Banning Pesticides, Limiting Fertilizer Application in the Corn Belt," American Journal of Agricultural Economics. Vol. 59(1):13-24, 1977.
- (72) Thomas, R. E. and D. M. Whiting.
Annual and Seasonal Precipitation Probabilities. U.S. Environmental Protection Agency, Vol. 600/2-77-182, August 1977.
- (73) Timmons, D. R., R. E. Burwell, and R. F. Holt.
"Nitrogen and Phosphorus Losses in Surface Runoff from Agricultural Land as Influenced by Placement of Broadcast Fertilizer," Water Resources Research. Vol. 9:658-667, 1973.
- (74) U.S. Dept. Agr., Forest Serv.
Non-Point Water Quality Modeling in Wildland Management: A State-of-the-Art Assessment. Volume II - appendixes, July 1977.
- (75) U.S. Dept. Agr., Agr. Res. Serv.
Present and Prospective Technology for Predicting Sediment Yields and Sources. Agr. Res. Serv. S-40. Oxford, Miss., Nov. 28-30, 1972.
- (76) U.S. Environmental Protection Agency.
Environmental Modeling and Simulation. Proceedings on the Conf. Apr. 19-22. U.S. Environmental Protection Agency, Vol. 600/9-76-016, July 1976.
- (77) Van Den Honert, T. H. and J. J. M. Hooyms.
"On the Absorption by Maize in Water Culture," Acta Bot Neerlandica. Vol. 43:376-384, 1955.
- (78) Viets, F. G., Jr.
"Animal Wastes and Fertilizers as Potential Sources of Nitrate Pollution of Water," Effects of Agricultural Production on Nitrates in Food and Water with Particular Reference to Isotope Studies. Vienna: International Atomic Energy Agency, pp. 63-76, 1974.

- (79) _____;
 "The Plant's Need for and Use of Nitrogen," Soil Nitrogen. Ed. W. V. Bartholomew and F. E. Clark. Agron. Monograph No. 10. Madison: American Society of Agronomists, 1965.
- (80) Whitaker, F. D., H. G. Heineman, and R. E. Burwell.
 "Fertilizing Corn with Less Nitrogen," Journal of the Soil Conservation Society of America. Jan.-Feb.:28-32, 1978.
- (81) Willrich, T. L. and G. E. Smith, ed.
Agricultural Practices and Water Quality. Results of a conf.: The Role of Agriculture in Clean Water. Ames, Iowa: Iowa State University, Nov. 18-20, 1969.
- Enrichment Ratios
- (82) Bouldin, D. R., W. S. Reid, and F. J. Lathwell.
 "Fertilizer Practices which Minimize Nutrient Loss," Agricultural Wastes: Principles and Guidelines for Practical Solutions. Proceedings of Cornell Univ. Conf. on Agr. Waste Management, Syracuse, N.Y., 1971.
- (83) Frere, M. H.
 "Integrating Chemical Factors with Water and Sediment Transport from a Watershed," Journal of Environmental Quality. Vol. 4(2):12-17, 1975.
- (84) Jacobs, J. J.
Controlling Sediment and Nutrient Losses from Agricultural Land. Cornell Agr. Econ. Staff Paper No. 72-20. September 1972.
- (85) Kasal, J.
Trade-Offs Between Farm Income and Selected Environmental Indicators: A Case Study of Soil Loss, Fertilizer, and Land Use Constraints. U.S. Dept. Agr., Econ. Res. Serv., Tech. Bull. No. 1550, August 1976.
- (86) Kelley, H. W.
 "Conservation Tillage Hazards Ahead?" Soil Conservation. Pp. 8-11, January 1977.
- (87) Klausner, S. D., P. J. Zwerman, and D. F. Ellis.
 "Surface Runoff Losses of Soluble Nitrogen and Phosphorus under Two Systems of Soil Management," Journal of Environmental Quality. Vol. 3: 42-46, 1974.
- (88) Porter, K. S., ed.
Nitrogen and Phosphorus: Food Production, Waste, and the Environment. Ann Arbor, Mich.: Ann Arbor Science, 1975.
- (89) Romkens, M. J. M., D. W. Nelson, and J. V. Mannering.
 "Nitrogen and Phosphorus Composition of Surface Runoff as Affected by Tillage Method," Journal of Environmental Quality. Vol. 2:292-295, 1973.

- (90) Ritchie, J. C., A. C. Gill, and J. R. McHenry.
"A Comparison of Nitrogen, Phosphorus, and Carbon in Sediments and Soils of Cultivated and Noncultivated Watersheds in the North Central States," Journal of Environmental Quality. Vol. 4(3):339-341, 1975.
- (91) Schaffer, W. H., Jr.
An Economic Analysis of Nitrogen, Phosphorus and Soil Loss from Agricultural Production Affecting Water Quality in a Small New York Watershed. Ph.D. thesis, Cornell Univ., June 1974.
- (92) Stanford, G.
"Rationale for Optimum Nitrogen Fertilization in Corn Production," Journal of Environmental Quality. Vol. 2:159-166, 1973.
- (93) Taylor, C. R. and K. K. Frohberg.
"The Welfare Effects of Erosion Controls, Banning Pesticides, and Limiting Fertilizer Application in the Corn Belt," American Journal of Agricultural Economics. Vol. 59(1):25-36, 1977.

Pesticide Monitoring

- (94) Bailey, G. W., R. R. Swank, and H. P. Nicholson.
"Predicting Pesticide Runoff from Agricultural Land: A Conceptual Model," Journal of Environmental Quality. Vol. 3(2):95-102, 1974.
- (95) Kellogg, R. L.
Dieldrin Contamination of Channel Catfish, Invertebrates and Minnows from the Des Moines River. MS thesis, available from National Technical Information Service, PB-251-046, Springfield, Va., 1974.
- (96) Mattraw, H. C., Jr.
"Occurrence of Chlorinated Hydrocarbon Insecticide, Southern Florida--1968-72," Pesticide Monitoring Journal. Vol. 9(2):106-114, 1975.
- (97) Pavlou, S. P., R. N. Dexter, and J. R. Clayton, Jr.
Chlorinated Hydrocarbons in Coastal Marine Ecosystems. Proceedings of the International Conf. on Transport of Persistent Chemicals in Aquatic Ecosystems, 1974.
- (98) Willis, G. H., L. L. McDowell, J. F. Parr, and C. E. Murphree.
Pesticide Concentrations and Yields in Runoff and Sediment from a Mississippi Delta Watershed. Proceedings of the Third Federal Inter-Agency Sedimentation Conf., Denver, Colo., pp. 3-53, 1976.
- (99) Willis, G. H., R. L. Rogers, and E. M. Southwick.
"Losses of Diuron, Linuron, Fenac, and Trifluralin in Surface Drainage Water," Journal of Environmental Quality. Vol. 4(3):399-402, 1976.

Pollutants from Other Nonpoint Sources

- (100) Baier, J. H. and K. A. Rykbost.
"The Contribution of Fertilizer to the Ground Water of Long Island,"
Ground Water. Vol. 14(6):439-447, 1976.
- (101) Baker, J. L., K. L. Campbell, H. P. Johnson, and J. J. Hanway.
"Nitrate, Phosphorus, and Sulfate in Subsurface Drainage Water,"
Journal of Environmental Quality. Vol. 4(3):406-412, 1975.
- (102) Barker, J. C. and J. I. Sewell.
Effects of Spreading Manure on Groundwater and Surface Runoff, Presented at the 1972 annual meeting, American Society of Agr. Engineers, Hot Springs, Ark., June 27-30, 1972.
- (103) Bondurant, J. A.
"Quality Surface Irrigation Runoff Water," Transactions of the American Society of Agricultural Engineers. Vol. 14(6), pp. 1,001-1,003, June 1971.
- (104) Branson, R. L., P. F. Pratt, J. D. Rhoades, and J. D. Oster.
"Water Quality in Irrigated Watersheds," Journal of Environmental Quality. Vol. 4(1):33-40, 1975.
- (105) Brodie, H. L. and J. T. Kennedy.
Land Disposal of Livestock Waste. Agr. Engineering Release No. 54, Environmental Series No. 5, Coop. Ext. Serv., Univ. of Maryland, College Park, 1972.
- (106) Bubenzer, G. D. and J. C. Converse.
Impact of Freezing and Thawing Soil Conditions on the Movement of Nutrients from Rural Lands. Wisconsin Water Resource Center, Madison, Wisc., 1975.
- (107) Burwell, R. E., G. E. Schuman, K. E. Saxton, and H. G. Heinemann.
"Nitrogen in Subsurface Discharge from Agricultural Watersheds,"
Journal of Environmental Quality. Vol. 5(3):325-329, 1976.
- (108) Carter, D. L., M. J. Brown, and J. A. Bondurant.
Sediment-Phosphorus Relations in Surface Runoff from Irrigated Lands. Proceedings of the Third Federal Inter-Agency Sedimentation Conf., Denver, Colo., pp. (3)41-(3)52, March 1976.
- (109) Chang, A. C., D. Aref, and D. C. Baier.
"Surface Runoff in Dairies," California Agriculture. Vol. 29(4):16-17, 1975.
- (110) Cross, O. E.
Pollutional Aspects and Crop Yields Resulting from High Manure Applications on Soil. Presented at the 1974 annual meeting, American Society of Agr. Engineers, Stillwater, Okla., June 23-26, 1974.

- (111) Daniels, R. B., J. W. Gilliam, E. E. Gamble, and R. W. Skaggs.
"Nitrogen Movement in a Shallow Aquifer System of the North Carolina Coastal Plain," Water Resources Bulletin. Vol. 11(6):1,121-1,130, 1975.
- (112) Gambrell, R. P., J. W. Gilliam, and S. B. Weed.
"Nitrogen Losses from Soils of the North Carolina Coastal Plain," Journal of Environmental Quality. Vol. 4(3):317-323, 1975.
- (113) Hortenstine, C. C. and R. B. Forbes.
"Concentrations of Nitrogen, Phosphorus, Potassium, and Total Soluble Salts in Soil Solution Samples from Fertilized and Unfertilized Histosols," Journal of Environmental Quality. Vol. 1(4):446-449, 1972.
- (114) Jackson, D. R., W. L. Lindsay, and R. D. Heil.
"The Impact of Molybdenum-Enriched Irrigation Water on Agricultural Soils Near Brighton, Colorado," Journal of Environmental Quality. Vol. 4(2):223-229, 1975.
- (115) Johnson, J. B.
Economic Impact of Selected Pollution Control Measures on Beef and Dairy Farms. Agr. Waste Conf., Michigan State Univ., East Lansing, pp. 31-43, May 22-23, 1974.
- (116) Keeney, D. R. and L. M. Walsh.
Sources and Fate of 'Available' Nitrogen in Rural Ecosystems. Proceedings of Conf. on Farm Animal Wastes, Nitrates, and Phosphates in Rural Wisconsin Ecosystems, Madison, Green Bay, and Eau Claire, Wisc., pp. 2-40, 1971.
- (117) Kreis, D. and W. Johnson.
"The Response of Macrobenthos to Irrigation Return Water," Journal of the Water Pollution Control Federation. Vol. 40(9):1,614-1,621, 1968.
- (118) Logan, T. J. and G. O. Schwab.
"Nutrient and Sediment Characteristics of Tile Effluent in Ohio," Journal of Soil and Water Conservation. Vol. 31(1):24-27, 1976.
- (119) Manges, H. L., L. S. Murphy, and W. L. Powers.
Summary of Kansas' Experience with Liquid Waste Spreading. Presented at Midwest Livestock Waste Management Conf., Ames, Iowa, Nov. 27-28, 1973.
- (120) Massie, L. R.
Planning Land Application of Manure. Proceedings of Conf. on Farm Animal Wastes, Nitrates, and Phosphates in Rural Wisconsin Ecosystems, Madison, Green Bay, and Eau Claire, Wisc., pp. 215-222, 1971.
- (121) O'Rear, C. W., Jr.
The Effects of Stream Channelization on the Distribution of Nutrients and Metals. North Carolina Water Resources Res. Institute, Report No. 108, Raleigh, August 1975.

- (122) Perez, A. I., W. C. Huber, J. P. Heaney, and E. E. Pyatt.
A Water Quality Model for a Conjunctive Surface-Groundwater System.
 Dept. of Environmental Engineering Sciences, Univ. of Florida, Gainesville, May 1974.
- (123) Schuman, G. E., T. M. McCalla, K. E. Saxton, and H. T. Knox.
 "Nitrate Movement and Its Distribution in the Soil Profile of Differentially Fertilized Corn Watersheds," Soil Science Society of America Proceedings. Vol. 39(6):1,192-1,197, 1975.
- (124) Seginer, I.
 "A Model for Surface Drainage of Cultivated Fields," Journal of Hydrology. Vol. 13(2):139-152, 1971.
- (125) Smolen, M. D., M. Rasnake, and V. O. Shanholtz.
Effect of Agricultural Drainage on Water Quality. Presented at the 1975 winter meeting, American Society of Agr. Engineers, Dec. 15-18, 1975.
- (126) Wallingford, G. W., L. S. Murphy, W. L. Powers, H. L. Manges, and L. A. Schmid.
 "Use of Cattle Feedlot Runoff in Crop Production," Wastewater Use in the Production of Food and Fiber--Proceedings. Oklahoma City, Okla., pp. 273-294, 1974.
- (127) Walter, M. F., T. S. Steenhuis, G. D. Bubenzer, and J. C. Converse.
Evaluation of a Soil Nitrate Transport Model. Presented at 1974 winter meeting, American Society of Agr. Engineers, Dec. 10-13, 1974.
- (128) Woods, C.
Agriculture's Pollution Solution for Lake Apopka. Sunshine State Agr. Res. Report, pp. 8-11, Sept.-Oct., 1973.
- (129) Young, C. P., D. B. Oakes, and W. B. Wilkinson.
 "Prediction of Future Nitrate Concentrations in Ground Water," Ground Water. Vol. 14(6):426-438.
- (130) Zwerman, P. J., S. D. Klausner, and D. R. Bouldin.
Surface Runoff Nutrient Losses from Various Land Disposal Systems for Dairy Manure. Proceedings of the 1972 Cornell Agr. Waste Management Conf., Ithaca, N.Y., pp. 495-502, 1972.

Sediment Sources

- (131) Foster, G. R. and W. H. Wischmeier.
 "Evaluating Irregular Slopes for Soil Loss Prediction," Transactions of the American Society of Agricultural Engineers. Vol. 17(3):305-309, 1974.

- (132) Harrold, L. L. and W. M. Edwards.
"No-Tillage System Reduces Erosion from Continuous Corn Watersheds,"
Transactions of the American Society of Agricultural Engineers. Vol.
17(3):414-416, 1974.
- (133) Heinemann, H. G. and F. D. Whitaker.
"Soil Cover Governs Soil Loss on United States Claypan Soils," Effects
of Man on the Interface of the Hydrological Cycle with the Physical
Environment. Proceedings of Paris Symposium, International Assn. of
Hydrological Sciences Publication No. 113, pp. 109-113, 1974.
- (134) Hindall, S. M.
Prediction of Sediment Yields in Wisconsin Streams. Proceedings of the
Third Federal Inter-Agency Sedimentation Conf., Denver, Colo., pp.
(1)204-(1)218, March 1976.
- (135) McCool, D. K., R. I. Papendick, and F. L. Brooks.
The Universal Soil Loss Equation as Adapted to the Pacific Northwest.
Proceedings of the Third Federal Inter-Agency Sedimentation Conf.,
Denver, Colo., pp. (2)135-(2)147, March 1976.
- (136) Midwest Research Institute.
Cost and Effectiveness of Control of Pollution from Selected Nonpoint
Sources. Prepared for the National Commission on Water Quality, Kansas
City, 1975.
- (137) Onstad, C. A., R. F. Piest, and K. E. Saxton.
Watershed Erosion Model Validation for Southwest Iowa. Proceedings of
the Third Federal Inter-Agency Sedimentation Conf., Denver, Colo., pp.
(1)22-(1)34, March 1976.
- (138) Roehl, J. W.
Sediment Source Areas, Delivery Ratios, and Intervening Morphological
Factors. J.A.S.H. Commission on Land Erosion, Publication No. 59, 1962.
- (139) Schneider, R. R.
"Planning Diffuse Pollution Control: An Analytical Framework," Water
Resources Bulletin. Vol. 14:322-336, 1978.
- (140) U.S. Environmental Protection Agency.
Environmental Impact of Land Use on Water Quality--Final Report on the
Black Creek Project. Environmental Protection Agency, Vol. 905/9-77-
007-A, October 1977.
- (141) Williams, J. R.
"Sediment Routing for Agricultural Watersheds," Water Research Bulle-
tin. Vol. 11(5):965-974, 1975.
- (142) Wischmeier, W. H.
"Estimating the Soil Loss Equation's Cover and Management Factor for
Undisturbed Areas," Present and Prospective Technology for Predicting
Sediment Yields and Sources. U.S. Dept. Agr., Agr. Res. Serv., S-40,
pp. 118-124, 1975.

- (143) _____.
"Use and Misuse of the Universal Soil Loss Equation," Journal of Soil and Water Conservation. Vol. 31(1):5-9, 1976.
- (144) _____, L. B. Johnson, and B. V. Cross.
"A Soil Erodibility Monograph for Farmland and Construction Sites," Journal of Soil and Water Conservation. Vol. 26(5):189-193, 1971.
- (145) Wischmeier, W. H. and D. D. Smith.
Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains. U.S. Dept. Agr., Agr. Res. Serv., Agr. Handbook No. 282, 1965.

ANALYZING CONTROL MEASURES AND THEIR COSTS

Discussion

Economic studies of soil conservation vary considerably in terms of size, ranging from national and regional linear programming models to studies of a single watershed. Between the watershed-size study and the regional model are river basin studies which are often large enough to offer limited regional implications.

National and Regional Models

The national models by Wade and Heady and Nicol, Heady, and Madsen emphasize the ability of U.S. agriculture to adjust to a common set of environmental restrictions (151, 148). Cost increases from substantial improvements in the environment are relatively small as less intensive production shifts to regions with steep, erosive soils. Limitations of the national model are clearly stated, including unresponsive output and input demands and the approximate nature of the soil loss estimates, especially from the standpoint of representing regional differences in potential soil losses. One could also argue that a common national sediment reduction goal is not applicable to existing legislation, which calls for identifying management practices on a regional basis. A national model may exaggerate the willingness of regions to sacrifice production to achieve a more uniform national water quality.

A study by Taylor and Froberg uses a stepped demand curve to analyze the cost of reducing erosion and nitrogen use in the Corn Belt (149). While maintaining the national perspective, emphasis is changed from regional shifts in the location of production to the overall cost of alternative sediment reductions. This cost is borne by consumers since farmers benefit from farm price increases as row crop production is reduced. Since less interregional substitution is possible, this model possibly overestimates the Corn Belt's share of costs from uniform national restrictions.

Small Area Economic Studies

Watershed linear programming models have the advantage over national and regional models of providing more accurate inputs into the USLE and of analyzing more realistic planning alternatives. The problem of accurately representing farm product demands for the smaller study area still exists, however. Assuming that product demands met by other areas are not affected by nonpoint pollution legislation leads to shifts in intensive production and its pollution to areas outside the study area (162, 172). On the other hand, assuming a fixed farm product demand for a watershed size area (using a cost minimization model) is hard to justify.

River basin studies generally fall between the watershed and the national/regional studies. Comprehensive studies of the major river basins in the late sixties and early seventies encompass some of the major crop-producing areas of the Nation. More recent studies, such as the USDA-State cooperative studies and those sponsored by the Water Resources Council cover smaller river basins and use more sophisticated analytic methods. Most of these studies assume a fixed demand, which appears justifiable for the larger basins.

In recent years, more studies have included estimates of changes in land use and farm income resulting from restrictions on soil losses. Obviously, production "goals" and alternative soil loss restrictions may not be compatible, but once this limitation of model assumptions is recognized, cost analysis can provide a common basis for 208 planners and traditional conservation professionals to weigh alternatives. Cost effective practices may then be determined according to the capabilities of each soil group (153, 165, 174).

Several authors compare costs of solving a local pollution problem through nonstructural management strategies, as opposed to structural solutions such as dredging. According to estimates by Workman and Keith (180), land treatment of fragile lands in the Upper Colorado River basin yields a maximum benefit-cost ratio of only 0.12. But for an Illinois watershed, Ouishi and Swanson found that farm conservation practices represent a very practical alternative to eventually dredging a recreational reservoir (172). This Illinois linear programming study attempts to measure tradeoffs between sediment control strategies and nitrate loss restrictions. Nitrate losses are simplistically related only to fertilizer levels, thus ignoring possible effects of soil conservation practices on nitrate losses. Another Illinois study finds that individual producers receive very modest long-term benefits to conservation practices, as compared to costs, from the standpoint of maintaining the productivity of their land (169). Conservation is thus practical for the public, but benefits are largely external to the farm firm.

Cost Sharing and Other Implementation Strategies

According to economic logic, achieving maximum resource allocation efficiency requires that the production unit bear the costs of reducing pollution. Otherwise, land may be used for growing crops which could be grown much more cheaply in another location. Failure to "internalize" pollution costs may also

lead to overinvestment in some crops and underinvestment in pasture or crops which cause less pollution (182).

Concern over nonpoint pollution raises the question of whether Federal programs which subsidize conservation practices should be expanded. Iowa, one of the first States to have a comprehensive sediment control law, bases its enforcement on obtaining cost sharing funds (183). Other States are likely to follow this example. Iowa's Senator Culver proposed additional Federal funding for conservation cost sharing, and \$400 million dollars per year has been designated for the Rural Clean Water Program (RCWP) by 1980.

Administration of the RCWP will determine how effectively subsidies will internalize social benefits from pollution abatement or discourage undesirable practices. During years of crop surplus, certain subsidies may conflict with programs to support farm income. The impact of each subsidy on farm income may therefore depend on market conditions which vary from year to year.

In spite of their superiority from a theoretical standpoint, measures forcing complete cost internalization are generally hard to implement. This review previously discussed complexities of matching management tools to field situations. For enforcing costly restrictions, legal problems can thus be anticipated from the difficulty of proving that farm management practices will lead to the desired improvement in water quality (186).

Among control measures, those requiring uniform reductions in effluent discharge appear the simplest to administer. However, they are also the most inefficient in that there is likely to be no equality of marginal costs among producers and no equality of marginal costs and benefits of compliance (182). Effluent taxes, while more efficient than uniform reductions in pollutant discharge, would clearly add to the administrative problems already stated, and create two new ones. First, they may add a tax burden to the pollution abatement costs (182). Second, a tax will likely distort the intended level of control, since it is difficult to select the optimum tax. Although Ackerman and associates suggest that effluent charges are much more precise in this respect (152), they would be difficult to administer for agriculture.

Bibliography

National and Regional Models

(146) Heady, E. O.

"Resource Adequacy in Limiting Nonpoint Pollution," Paper No. 76-2562, presented at the 1976 winter meeting, American Society of Agr. Engineers, December 1976.

(147) _____, K. J. Nicol, and J. C. Wade.

"Economic Trade-Offs to Limit Nonpoint Sources of Agricultural Pollution," Water, Air, and Soil Pollution. Vol. 5(4):415-430, 1976.

- (148) Nicol, K. J., E. O. Heady, and H. C. Madsen.
Models of Soil Loss, Land and Water Use, Spatial Agricultural Structure, and the Environment. CARD Report, Iowa State Univ., Ames, Iowa, 1974.
- (149) Taylor, C. R. and K. K. Frohberg.
"The Welfare Effects of Erosion Controls, Banning Pesticides, and Limiting Fertilizer Application in the Corn Belt," American Journal of Agricultural Economics. Vol. 59(1):25-36, 1977.
- (150) Vocke, G. F., E. O. Heady, W. G. Boggess, and H. J. Stockdale.
Economic Impacts on U.S. Agriculture from Insecticide, Fertilizer, Soil Loss, and Animal Waste Regulatory Policies. CARD Report 73, Iowa State Univ., Ames, Iowa, 1977.
- (151) Wade, J. C. and E. O. Heady.
"Controlling Nonpoint Sediment Sources with Cropland Management: A National Economic Assessment," American Journal of Agricultural Economics. Vol. 59(1):13-24, 1977.

Small Area Economic Studies

- (152) Ackerman, B. A.
The Uncertain Search for Environmental Quality. London: Collier MacMillan Publishers, 1974.
- (153) Alt, K. F.
An Economic Analysis of Field Crop Production, Insecticide Use, and Soil Erosion in a Subbasin of the Iowa River. Unpublished Ph.D. thesis, Iowa State Univ., 1976.
- (154) _____.
Impacts of Erosion Controls Upon Agriculture of an Iowa Watershed. Presented at the 88th annual session, Iowa Academy of Sciences, 1976.
- (155) _____ and E. O. Heady.
Economics and the Environment: Impacts of Erosion Restraints on Crop Production in the Iowa River Basin. CARD Report 75, Iowa State Univ., 1977.
- (156) _____ and J. A. Miranowski.
"Social Costs and Effectiveness of Alternative Nonpoint Pollution Control Policies," forthcoming in Best Management Practices for Agriculture and Silviculture. Proceedings of the 10th Annual Cornell Conf., Rochester, N.Y., 1978.
- (157) Cosper, H. R.
Economic Impact of Sediment Management in a Multiple-Use Watershed of North Central Mississippi. Working Paper No. 40, 1977.
- (158) Doll, R. J.
"Economic Impact of Agricultural Pollution Control Programs," Waste Management Research. Pp. 9-16, 1972.

- (159) Forster, D. L. and G. S. Becker.
Erosion Control: Costs and Income Distribution Under Regulation, Tax and Subsidy. Annual meetings, 1978, American Agr. Econ. Assn.
- (160) Greiner, W. H.
"Iowa's Experience with a Sediment Control Law," Journal of Soil and Water Conservation. Vol. 30(3):132-134, 1975.
- (161) Guntermann, K.
Soil Loss from Illinois Farms: Economic Analysis of Productivity Loss and Sedimentation Damage. Available from National Technical Information Service, PB-241-584, Springfield, Va., December 1974.
- (162) Jacobs, J. J.
Controlling Sediment and Nutrient Losses from Agricultural Land. Cornell Agr. Econ. Staff Paper No. 72-20. September 1972.
- (163) _____.
Economics of Water Quality Management: Exemplified by Specific Pollutants in Agricultural Runoff. Ph.D. thesis, Iowa State Univ., Ames, 1972.
- (164) _____ and J. F. Timmons.
"An Economic Analysis of Agricultural Land Use Practices to Control Water Quality," American Journal of Agricultural Economics. Vol. 56: 796-798, 1974.
- (165) Kasal, J.
Trade-Offs Between Farm Income and Selected Environmental Indicators: A Case Study of Soil Loss, Fertilizer, and Land Use Constraints. U.S. Dept. Agr., Econ. Res. Serv., Tech. Bull. No. 1550. August 1976.
- (166) Lee, M. T.
Economic Analysis of Erosion and Sedimentation Hambaugh-Martin Watershed. Univ. of Illinois, IIEQ Doc. No. 72-28, 1974.
- (167) _____, A. S. Narayanan, and E. R. Swanson.
Economic Analysis of Erosion and Sedimentation, Sevenmile Creek Southwest Branch Watershed. Univ. of Illinois, IIEQ Doc. No. 74-30, 1974.
- (168) Minnesota Pollution Control Agency.
Report on the Investigation of Water Quality of Christmas Lake Watershed. Division of Water Quality Report, January 1975.
- (169) Narayanan, A. S.
Economic Analysis of Erosion and Sedimentation--Mendota West Fork Watershed. Univ. of Illinois, IIEQ Doc. No. 74-13, 1974.
- (170) _____, M. T. Lee, and E. R. Swanson.
Economic Analysis of Erosion and Sedimentation--Crab Orchard Lake Watershed. Univ. of Illinois, IIEQ Doc. No. 74-29, 1974.

- (171) Economic Analysis of Erosion and Sedimentation--Lake Glandale Watershed. Univ. of Illinois, IIEQ Doc. No. 74-40, 1974.
- (172) Ouishi, O. and E. R. Swanson.
"Effect of Nitrate and Sediment Constraints on Economically Optimal Crop Production," Journal of Environmental Quality. Vol. 3(3):234-238, 1974.
- (173) Porter, K. S. (ed.).
Nitrogen and Phosphorus: Food Production, Waste and the Environment. Ann Arbor, Mich.: Ann Arbor Science, 1975.
- (174) Putman, J., S. Stipe, and J. McDivitt.
A Summary of the Linear Programming Analysis for the Maumee Level B River Basin Study. U.S. Dept. Agr., Econ. Res. Serv., Administrative Paper, East Lansing, Mich., 1977.
- (175) Schoneman, D. F.
Impact of Nitrate Fertilizer Restrictions on Salt River Project and Roosevelt Water Conservation District Growers. Master of Science thesis, Arizona Univ., Tucson, Ariz., 1974.
- (176) Seay, E. E., Jr.
Minimizing Abatement Costs of Water Pollutants from Agriculture: A Parametric Linear Programming Approach. Ph.D. dissertation, Iowa State Univ., Ames, 1970.
- (177) Sewell, J. I. and J. M. Alphin.
Effects of Agricultural Land Uses on Runoff Quality. Animal Waste Management Facilities and Systems, Bull. 548, Univ. of Tennessee, Knoxville, July 1975.
- (178) Taylor, C. R. and E. R. Swanson.
"Economic Impact of Imposing Per Acre Restrictions on the Use of Nitrogen Fertilizer in Illinois," Illinois Agricultural Economics. Vol. 14(2):1-6, 1974.
- (179) Walker, M. E., Jr. and E. R. Swanson.
"Economic Effects of a Total Farm Nitrogen Balance Approach to Reduction of Potential Nitrate Pollution," Illinois Agricultural Economics. Vol. 14(2):21-27, 1974.
- (180) Workman, J. P. and J. E. Keith.
"Economics of Soil Treatments in the Upper Colorado," Watershed Management. Pp. 591-596, August 1975.

Cost Sharing and Other Implementation Strategies

- (181) Campbell, H. F.
"On the Income Distributional Effects of Environmental Management Policies," Water Resources Research. Vol. 12(5):1,077-1,080, 1976.

- (182) Casler, G. L. and J. J. Jacobs.
Internalizing Externalities of Phosphorus Discharges from Crop Production to Surface Water: Effluent Taxes vs. Uniform Reductions. Discussion paper. Annual meetings, American Agr. Econ. Assn., 1977.
- (183) Greiner, W. H.
"Iowa's Experience with a Mandatory Sediment Control Law," Journal of Soil and Water Conservation. Vol. 30(3):132-134, 1975.
- (184) Miller, W. and J. H. Gill.
"Equity Considerations in Controlling Nonpoint Pollution from Agricultural Sources," Water Resources Bulletin. Vol. 12(2):253-257, 1976.
- (185) Rueter, F. H. and P. Kushner.
Economic Incentives for Land Use Control. Off. Res. and Dev., U.S. Environmental Protection Agency, Vol. 600/5-77-001, February 1977.
- (186) Seitz, W. D.
Alternative Policies for Control of Nonpoint Sources of Water Pollution from Agriculture. Univ. of Illinois at Urbana, 1978.

POLLUTION DYNAMICS IN RURAL LAKES, STREAMS, AND ESTUARIES

Discussion

Studies of pollutant delivery through streams and eventual impacts on lakes and estuaries try to provide a link between agricultural conservation systems and current plans for achieving specific improvements in measured water quality. Although a number of studies are referenced, the link between onsite farm management practices and measurements of stream water quality is generally weak. This weakness becomes especially evident as planners attempt to locate sources of measured pollution problems during particular storms.

Stream Modeling and Pollutant Delivery

Nitrogen delivery is a particularly vexing problem, since nitrogen can change forms in a stream as well as disappear from the water system through denitrification and atmosphere N fixation (200).

Sediment and phosphorus share another transport problem: phosphorus is adsorbed to sediment and both are then deposited or removed from the bottom of streams depending on characteristics of streams and storms (188, 197). This also complicates separating the nonpoint contributions from point sources and bank erosion. To develop an effective cleanup strategy for a particular lake or estuary, it is important to know how much nutrient or sediment loss from fields at different river reaches is carried to the target area.

The importance of transport variables also will vary, depending on whether water quality objectives emphasize receiving waters or include improving streams as well. Sediment, for instance, causes some degree of damage to wildlife cover in streams and aggravates flood damage, as well as causing damage to receiving lakes and reservoirs (189). It also can be argued, however, that sediment and phosphorus reaching any location in a stream system are available for future transport to problem areas.

One way of reducing the cost of pollution control is to narrow the geographic area that requires stringent control measures. Since lakes and certain estuaries are most easily damaged by pollutants, knowledge of transport systems is a prerequisite to locating and controlling contributing sources.

Pesticide Impacts and Environmental Exposure Indices

Given the number of pesticides on the market, there is an added challenge of representing typical relationships for major classes of pesticides. The vast array of pesticides of different chemical and physical makeup makes generalization difficult, even within classes of similar materials. The concept of environmental exposure indices was developed to help reduce this complexity to a common measure which can be computed for pesticide regimens and used for comparison between them. Indices by Weber combine such characteristics as toxicity, soil persistence, and bioaccumulation ratios into a single measure (211). Environmental exposure indices are easily incorporated into economic models such as Alt's linear programming model (210). While pesticide characteristics are included in the indices, inability to incorporate specific soil, climate, and especially tillage practices limits their usefulness.

Movement and Fate of Pesticides

Pesticides' behavior in the environment is under intensive laboratory and field examination. These studies emphasize discovery of the mechanisms by which pesticides are dispersed from the application site, the rates at which pesticides degrade to harmless residues, and their effects on organisms between application and complete degradation. Pesticides that are slow to degrade and adhere strongly to sediment are most responsive to soil conservation practices.

Some studies concentrate on the transport problem, examining dependencies between dissolved and adsorbed states on environmental factors such as temperature and moisture (214, 215). An approach more closely related to economic studies examines the effects of agricultural practices, especially irrigation, on pesticide movement in the soil (221).

Other studies focus on transformations of pesticides occurring once the material leaves the land surface. Such transformations may occur in surface water or in the ground water system (223, 224). Studies of the effect of pesticides on the environment, particularly on aquatic organisms, carry this kind of analysis to a logical conclusion. Two kinds of these studies can be differentiated by methodology employed. First are continuous flow studies in which organisms are subjected to a continuous level of pesticides and the effects on behavior and bioaccumulation are noted (217, 218). A second kind of study uses a

model ecosystem which exposes organisms to conditions analogous to those in nature (219). This method is more useful in that it permits incorporation of typical agricultural conditions and analysis of the effects of alternate practices (220).

A more complete approach follows pesticides from application through transport, degradation, and bioaccumulation (222). This permits viewing the entire process in a unified manner, obviating the need to piece together separate research conducted under dissimilar conditions. Unfortunately, little such complete approach research has been done, particularly regarding the effects of specific conservation practices such as no-till, with its higher pesticide use and reduction in pesticide transport by erosion.

Simulation of Pesticide Movement

Many of the studies discussing pesticide movement incorporate and test mathematical models of various transport mechanisms (215, 221). Attempts at consolidating numerous separate relations into more general and comprehensive models of pesticide movement and transformation for simulation via digital computer have been made (225, 226, 227). While achieving varying degrees of generality and accuracy, these simulation models offer a potentially important tool to examine the environmental impacts of alternate agricultural practices.

Issues Unique to Lakes

Perhaps the most visible pollution problems occur in lakes. These may or may not involve health hazards and do not usually lead to destruction of wildlife, but they can affect the esthetic enjoyment and usefulness of unique environmental or recreational amenities. Much of the nutrient and sediment loss from agriculture will have visible effects in lakes. These take the form of algae blooms, murky or shallow water, and dense weed growth.

The frequency of such problems, however, may depend as much on the nature of the receiving body of water as on the magnitude of effluent loads. Therefore, efforts to control lake problems need to consider which nutrient is limiting for algae growth and the levels which local lakes are capable of absorbing safely.

Procedures for determining whether the nitrogen or phosphorus is limiting (201, 244) are fairly simple. Usually it is the latter. For a given level of nutrient input, warm, shallow lakes with slow turnover are most affected by algae growth. Turbidity or murkiness from suspended sediment also will limit algae growth.

Simple models of lake trophic status are available (237, 243). These models are useful both from the standpoint of assessing the potential for success of phosphorus and nitrogen reduction programs and for setting meaningful water quality goals. Fixed standards based only on regional concentration goals might again lead to expensive reductions in nutrient losses in watersheds where none is needed, or to a failure to provide a stricter standard where it is required for preventing excessive growth of weeds and algae.

Alternative Measures for Lake Problems

Lake destratification techniques and use of chemicals to precipitate out phosphate ions provide short-term solutions to algae growth from nutrients, just as sediment traps and dredging can alleviate effects of sedimentation (250, 252). The cost and obvious side effects of some of these practices, such as noisy disruptions or chemical buildups, probably limit their consideration as alternatives to pollution reduction. It is conceivable, however, that further water research will lead to structural or biological alternatives to the more stringent nutrient management practices on farms. Several studies of this nature are referenced.

Estuary Problems

The immense size of some contributing drainage areas creates a special set of concerns for estuaries. The problems of analyzing delivery systems are therefore particularly relevant to locating pollution sources for estuaries. References indicate that estuary environments present their own unique set of problems due to plant growth characteristics (262) and to effects of tidal currents which add to the problems of locating pollutant sources (261).

Bibliography

Stream Modeling and Pollutant Delivery

- (187) Akers, C. R.
Sedimentation of a Flatland Watershed in Louisiana. Proceedings of the Third Federal Inter-Agency Sedimentation Conf., Denver, Colo., pp. 1-74, 1976.
- (188) Bouldin, D. R., A. H. Johnson, and D. A. Lauer.
"Transport in Streams," Nitrogen and Phosphorus; Food Production, Waste and the Environment. Ed. K. S. Porter. Ann Arbor: Ann Arbor Science Inc., 1975.
- (189) Cahill, T. H., P. Imperato, P. K. Nebel, and F. H. Verhoff.
Phosphorus Dynamics and Transport in the Brandywine Basin. Technical Paper No. 3. Tri-County Conservancy of the Brandywine, Inc., Chadds Ford, Pa., January 1975.
- (190) Cairns, J., Jr. and K. L. Dickson.
An Ecosystematic Study of the South River, Virginia. Water Resources Res. Center, Virginia Polytechnic Institute and State Univ., Blacksburg, 1972.

- (191) Clark, L. J., V. Guide, and T. H. Pfeiffer.
Summary and Conclusions: Nutrient Transport and Accountability in the Lower Susquehanna River Basin. U.S. Environmental Protection Agency, Annapolis, Md., 1974.
- (192) Delfino, J. J. and D. J. Byrnes.
The Influence of Hydrological Conditions on Dissolved and Suspended Constituents in the Missouri River. Wisconsin Univ., Madison Laboratory of Hygiene, 1975.
- (193) Hadley, R. F. and L. M. Shown.
Relation of Erosion to Sediment Yield. Water Resources Division, Geological Survey, Lakewood, Colo., 1975.
- (194) Haith, D. A.
"Land Use and Water Quality in New York Rivers," Journal of the Environmental Engineering Division. ASCE, Vol. 102(EEL), proceedings paper 11902, pp. 1-15, 1975.
- (195) Haney, J. T.
"Phosphorus in New York State Rivers: Sources, Sinks, and Detergents." Dept. of Chemistry, State Univ. of New York at Binghamton, 1973.
- (196) Hines, W. G., D. A. Rickert, S. W. McKenzie, and J. P. Bennett.
Formulation and Use of Practical Models for River-Quality Assessment. River-Quality Assessment of the Willamette River Basin, Oregon. Geological Survey Circular 715-B, 1975.
- (197) Kunishi, H. M., A. W. Taylor, W. R. Heald, W. J. Gburek, and R. N. Weaver.
"Phosphate Movement from an Agricultural Watershed During Two Rainfall Periods," Journal of Agriculture and Food Chemistry. Vol. 20:900-905, 1974.
- (198) McElroy, A. D., F. Y. Chiu, and A. Aleti.
Analysis of Nonpoint-Source Pollutants in the Missouri Basin Region. Midwest Res. Institute, Kansas City, Mo., U.S. Environmental Protection Agency, Vol. 600/5-75-004, March 1975.
- (199) Moore, B. R.
Hydraulic and Flow Studies Related to Sediment Transport, Kentucky River, Kentucky. Kentucky Water Resources Institute, Lexington, 1974.
- (200) Pionke, H.
Report to the Northeast Regional Section 208. Interagency Committee, State College, Pa., 1977.
- (201) Rickert, S. A., R. R. Petersen, S. W. McKenzie, W. G. Hines, and S. A. Wille.
Algal Conditions and the Potential for Future Algal Problems in the Willamette River, Oregon. River-Quality Assessment of the Willamette River Basin, Oregon. Geological Survey Circular 715-G, 1977.

- (202) Rosgen, D. L.
The Use of Color Infrared Photography for the Determination of Suspended Sediment Concentrations and Source Areas. Proceedings of the Third Federal Inter-Agency Sedimentation Conf., Denver, Colo.; pp. 7-42, 1976.
- (203) Sayre, W. W.
Dispersion of Mass in Open-Channel Flow. Colorado State Univ., Fort Collins. Hydrology Papers, No. 75, August 1975.
- (204) Southerland, E. V.
Agricultural and Forest Land Runoff in Upper South River Near Waynesboro, Virginia. Virginia Polytechnic Institute and State Univ., Blacksburg. Dept. of Environmental Sciences and Engineering, 1974.
- (205) Steele, T. D., E. J. Gilroy, and R. O. Hawkinson.
An Assessment of Areal and Temporal Variations in Streamflow Quality Using Selected Data from the National Stream Quality Accounting Network. Geological Survey open-file report 74-217, August 1974.
- (206) U.S. Environmental Protection Agency.
Relationships Between Drainage Area Characteristics and Non-Point Source Nutrients in Streams. Pacific Northwest Environmental Res. Laboratory, Corvallis, Ore., 1976.
- (207) Vannote, R. L. and R. C. Ball.
Community Productivity and Energy Flow in an Enriched Warm-Water Stream. Dept. of Fisheries and Wildlife, Michigan State Univ., East Lansing, 1972.
- (208) Wang, W. C.
Effect of Turbidity on Algal Growth. Illinois State Water Survey, Urbana, 1974.
- (209) Weiss, C. M.
Long Term Trends in Water Quality, Lower Haw and New Hope Rivers - 1966-1973. Dept. of Environmental Sciences and Engineering. Univ. of North Carolina, Chapel Hill, 1974.

Pesticide Impacts and Environmental Exposure Indices

- (210) Alt, K. R.
Economic Analysis of Field Crop Production, Insecticide Use, and Soil Erosion in a Subbasin of the Iowa River. Unpublished Ph.D. thesis, Iowa State Univ., 1976.
- (211) Weber, J. B.
"The Pesticide Scorecard," Environmental Science and Technology. Vol. 11(8), 1977.

- (212) Crawford, N. H. and A. S. Donigian, Jr.
Pesticide Transport and Runoff Model for Agricultural Lands. U.S. Environmental Protection Agency, Vol. 660/2-74-013, December 1973.
- (213) Davidson, J. M., G. H. Brusewitz, D. R. Baker, and A. L. Wood.
Use of Soil Parameters for Describing Pesticide Movement Through Soils. U.S. Environmental Protection Agency, Vol. 660/2-75-009, May 1975.
- (214) Huang, J. C.
Water-Sediment Distribution of Chlorinated Hydrocarbon Pesticides in Various Environmental Conditions. Proceedings of the International Conf. on Transport of Persistent Chemicals in Aquatic Ecosystems, pp. 11-30, May 1974.
- (215) Johnson, H. P. and J. L. Baker.
Movement of Herbicides in Soil by Mass Flow. Available from National Technical Information Service, PB 248-455, Springfield, Va., June 1975.
- (216) Leonard, R. A., G. W. Bailey, and R. R. Swank, Jr.
"Transport, Detoxification, Fate, and Effects of Pesticides in Soil and Water Environments," Land Application of Waste Materials. Soil Conservation Society of America, Akeny, Iowa, 1976.
- (217) Macek, K. J., M. E. Barrows, R. F. Frasnay, and B. H. Sleight.
Bioconcentration of ¹⁴C-Pesticides by Bluegill Sunfish During Continuous Aqueous Exposure. International Joint Commission Symposium on Structure Activity Correlations in Studies of Toxicity and Bioconcentration with Aquatic Organisms, Burlington, Ont.: Canada Center for Inland Waters, pp. 119-142, 1975.
- (218) Mayer, F. L., Jr., P. M. Mehrle, Jr., and W. P. Dwyer.
Toxaphene Effects on Reproduction, Growth, and Mortality of Brook Trout. Available from National Technical Information Service, PB-249-303, Springfield, Va., 1975.
- (219) Metcalf, R. L. and J. R. Sanborn.
"Pesticides and Environmental Quality in Illinois," Illinois Natural History Survey Bulletin. Vol. 31(9):381-436, 1975.
- (220) Sanborn, J. R.
The Fate of Select Pesticides in the Aquatic Environment. U.S. Environmental Protection Agency, Vol. 660/3-74-025, December 1974.
- (221) Selim, H. M., R. S. Mansell, and A. Elzeftawy.
"Distributions of 2,4D and Water in Soil During Infiltration and Redistribution," Soil Science. Vol. 121(3):176-183, 1976.

- (222) Simsiman, G. V., G. Chesters, and T. C. Daniel.
"Diquat and Endothall: Their Fates in the Environment," Residue Reviews. Vol. 62:131-174, 1976.
- (223) Weidner, C. W.
Degradation in Groundwater and Mobility of Herbicides. Available from National Technical Information Service, PB-239-242, Springfield, Va., June 1974.
- (224) Wolfe, N. L., R. G. Zepp, G. L. Baughman, R. C. Fincher, and J. A. Gordon.
Chemical and Photochemical Transformation of Selected Pesticides in Aquatic Systems. U.S. Environmental Protection Agency, Vol. 600/3-76-067, September 1976.

Simulation of Pesticide Movement

- (225) Adams, R. T. and F. M. Kurisu.
Simulation of Pesticide Movement on Small Agricultural Watersheds. U.S. Environmental Protection Agency, Vol. 600/3-76-066, Ecological Res. Series, September 1976.
- (226) Bruce, R. R.
"A Model for Runoff of Pesticides from Small Upland Watersheds," Journal of Environmental Quality. Vol. 4(4):541-548, 1975.
- (227) Crawford, N. H. and A. S. Donigian, Jr.
Pesticide Transport and Runoff Model for Agricultural Lands. U.S. Environmental Protection Agency, Vol. 660/2-74-013, December 1973.

Issues Unique to Lakes

- (228) American Water Works Association.
"Water-Supply Reservoirs: How Much Storage Space Remains?" Journal of the American Water Works Association. Vol. 67(12):674-678, 1975.
- (229) Anderson, D. R.
"Water Quality Modeling of Deep Reservoirs," Journal of the Water Pollution Control Federation. Vol. 48(1):134-146, 1976.
- (230) Arce, R. G. and C. E. Boyd.
"Effects of Agricultural Limestone on Water Chemistry, Phytoplankton Productivity, and Fish Production in Soft Water Ponds," Trans-American Fishery Society. Vol. 2:308-312, 1975.
- (231) Cheetham, R. N., Jr. and R. F. Wilke.
Sedimentation in Birch Lake, Iowa County, Wisconsin. Proceedings of the Third Federal Inter-Agency Sedimentation Conf., Denver, Colo., pp. (1)110-(1)122, March 1976.

- (232) Churchill, C. L., C. K. Brashier, and C. S. Johnson.
Silt Removal from a Lake Bottom. Available from National Technical Information Service, PB-241-250, Springfield, Va., February 1975.
- (233) Fan, S. S.
The Role of Sediment Problems in Hydroelectric Development. Proceedings of the Third Federal Inter-Agency Sedimentation Conf., pp. 4-149 - 4-161, 1976.
- (234) Finnemore, E. J. and J. L. Shepherd.
Spokane River Basin Model Project: Volume 1 - Final Report. Air and Water Programs Division, October 1974.
- (235) Gorham, E.
"Some Relationships Between Algal Standing Crop, Water Chemistry, and Sediment Chemistry in the English Lakes," Limnology and Oceanography. Vol. 19(4):601-617, 1974.
- (236) Hartke, E. J. and J. R. Hill.
Sedimentation in Lake Lemon, Monroe County, Indiana. Indiana Geological Survey, 1974.
- (237) Larsen, D. P. and H. T. Mercier.
Lake Phosphorus Loading Graphs: An Alternative. Available from National Technical Information Service, PB-243-869, Springfield, Va., July 1975.
- (238) Li, W. C., D. E. Armstrong, and R. F. Harris.
Biological Availability of Sediment Phosphorus to Macrophytes. Available from National Technical Information Service, PB-239-269, Springfield, Va., 1974.
- (239) Miller, W. E., T. E. Maloney, and J. C. Greene.
"Algal Productivity in 49 Lake Waters as Determined by Algal Assays," Water Research. Vol. 8:667-679, 1974.
- (240) Schieve, F. R., J. C. Ritchie, and J. R. McHenry.
Suspended Sediment, Solar Radiation and Heat in Agricultural Reservoirs. Proceedings of the Third Federal Inter-Agency Sedimentation Conf., Denver, Colo., pp. (3)1-(3)12, March 1976.
- (241) Shannon, E. E. and P. L. Brezonik.
"Relationships Between Lake Trophic State and Nitrogen Phosphorus Loading Rates," Environmental Science and Technology. Vol. 6(8):719-725, 1972.
- (242) Sievert, A. C.
"The Effects of Agricultural Run-off and Siltation on a New Recreational Lake," Transactions of the Illinois Academy of Science. Vol. 68(4): 369-380, 1975.
- (243) Snodgrass, W. J., and C. R. O'Melia.
"Predictive Model for Phosphorus in Lakes," Environmental Science and Technology. Vol. 9(10):937-944, 1975.

- (244) Stumm, W. and J. J. Morgan.
Aquatic Chemistry. New York: Wiley Interscience, 1970.
- (245) Tapp, John S.
Comparison of Eutrophication Models. Mimeo, U.S. Environmental Protection Agency, Technical Support Branch, Atlanta, 1978.
- (246) U.S. Environmental Protection Agency.
A Compendium of Lake and Reservoir Data Collected by the National Eutrophication Survey in the Northeast and Northcentral United States. Pacific Northwest Environmental Research Laboratory. Available from National Technical Information Service, PB-248-894, Springfield, Va., November 1975.
- (247) _____.
National Eutrophication Survey Methods for Lakes Sampled in 1972. Pacific Northwest Environmental Research Laboratory. Available from National Technical Information Service, PB-240-936, Springfield, Va., October 1974.
- (248) Williams, J. D. H., T. P. Murphy, and T. Mayer.
"Rates of Accumulation of Phosphorus Forms in Lake Erie Sediments," Journal of the Fishery Research Board. Vol. 33(3):430-439, 1976.

Alternative Measures for Lake Problems

- (249) Eisenreich, S. J., D. E. Armstrong, and R. F. Harris.
A Chemical Investigation of Phosphorus Removal in Lakes by Aluminum Hydroxide. Water Chemistry Laboratory, Wisconsin Univ., Madison, 1977.
- (250) Garton, J. E. and C. E. Rice.
Improving the Quality of Water Releases from Reservoirs by Means of a Large Diameter Pump. Dept. of Agr. Engineering, Oklahoma State Univ., Stillwater, 1976.
- (251) Keating, K. E.
Algal Metabolite Influence on Bloom Sequence in Eutrophied Freshwater Ponds. Haskins Laboratories, Inc., U.S. Environmental Protection Agency, Vol. 600/3-76-081, New Haven, Conn., 1976.
- (252) Lorenzen, M. W. and R. Mitchell.
"An Evaluation of Artificial Destratification for Control of Algal Blooms," Journal of the American Water Works Association. Vol. 67(7): 373-376, 1975.
- (253) Peterka, J. J. and J. W. Held.
Causes and Control of Algal Blooms in Spiritwood Lake, North Dakota. Dept. of Zoology, North Dakota State Univ., Fargo, 1972.
- (254) Sanville, W. D., A. R. Gahler, J. A. Searcy, and C. F. Powers.
Studies on Lake Restoration by Phosphorus Inactivation. Corvallis Environmental Res. Laboratory, Oregon, 1976.

- (255) Toetz, D. W.
Biological and Water Quality Effects of Artificial Destratification of Lake of the Arbuckles. School of Biological Sciences, Oklahoma State Univ., Stillwater, 1975.
- (256) Wolverton, D. C. and R. C. McDonald.
Water Hyacinths and Alligator Weeds for Removal of Lead and Mercury from Polluted Waters. National Space Technology Laboratories, St. Louis, Mo., 1975.

Estuary Problems

- (257) Brokaw, R. and G. F. Oertel.
"Suspended Sediment Data from Nearshore Waters of Georgia," Technical Report Series No. 76-3. 1976.
- (258) Conover, S. A. M.
"Nitrogen Utilization During Spring Blooms of Marine Phytoplankton in Bedford Basin, Nova Scotia, Canada," Marine Biology. Vol. 32(3), 1975.
- (259) Faust, M. A.
"Coliform Bacteria from Diffuse Sources as a Factor in Estuarine Pollution," Water Research. Vol. 10(7):619-627, 1976.
- (260) Hester, J. M. and B. J. Copeland.
Nekton Population Dynamics in the Albemarle Sound and Neuse River Estuaries. Available from National Technical Information Service, COM-75-10480, Springfield, Va., January 1975.
- (261) O'Connor, D. J., R. V. Tomann, and D. M. DiToro.
Dynamic Water Quality Forecasting and Management. U.S. Environmental Protection Agency, Vol. 660/3-73-009, 1973.
- (262) Prakash, A.
"Land Drainage as a Factor in 'Red Tide' Development," Environmental Letters. Vol. 9(2):121-128, 1975.

BENEFITS OF WATER QUALITY IMPROVEMENT

Evaluation of benefits of water quality improvement tends to be highly subjective. Information about public perceptions of nonpoint problems is therefore very relevant when measuring economic and environmental tradeoffs.

Discussion

If a pesticide is causing health problems, technical measurement of safe levels can serve as criteria for goal attainment. Loss of reservoir capacity

can be converted to dollar values for cost-benefit comparisons. But where periodic green algae or odors or heavy siltation from agriculture visibly pollute an area, it is not clear which problem merits the most intensive investment.

Studies of public perceptions have sometimes concentrated on overall interest in water quality versus other goals (268, 269), rather than weighing public preferences between alternative goals for local water quality improvements.

Presumably, measurement of perceived benefits from attaining alternative goals could focus nonpoint planning on investments in controls which yield the highest amenity benefits. For instance, if a midwestern State was primarily concerned about algae problems for scarce lake resources, then nutrient loads from streams entering the Missouri River might receive less attention. In the absence of good studies of public perceptions, arbitrary technical standards will probably serve as goals. Bruce Ackerman and associates have demonstrated that this can occur under the most technologically competent planning efforts (263).

Dornbusch and Barranger measure benefits of pollution control as reflected in property values (272). Walsh and associates study water quality benefits for recreation (285).

Planning studies also provide insights into public perceptions, either directly if they undertake attitude surveys, or through study inputs from elected officials and interest group leaders. Although only limited information of this type is available (280), studies funded under Section 208 of the Pollution Control Act are expected to be an important future source of information. Studies of State legislative and executive agency involvement in water quality planning also provide indirect knowledge of public concerns by showing how ongoing programs are related to the new emphasis on water quality (274, 284). Planning relationships with ongoing Federal conservation programs are also relevant (278, 281, 282).

Bibliography

- (263) Ackerman, B. A.

The Uncertain Search for Environmental Quality. London: Collier MacMillan Publishers, 1974.

- (264) Althoff, P. and W. H. Greig.

"Environmental Pollution Control: Two Views from the General Public," Environment and Behavior. Vol. 9(3):441, 1977.

- (265) Ben, M.

"The Effects of Water Pollution from Non-Point Sources as it Relates to the Health of Man," Economics of a Clean Environment. McLean, Va., pp. 415-425, 1974.

- (266) Boggess, W. G., J. A. Miranowski, K. F. Alt, and E. O. Heady.
Sediment Delivery and Farm Production Costs--A Multiple Objective Analysis. Presented at the Southern Agr. Econ. Assn. Annual Meeting, Houston, February 1978.
- (267) Brinkley, C. S. and W. M. Haneman.
The Recreation Benefits of Water Quality Improvement: Analysis of Day Trips in an Urban Setting. U.S. Environmental Protection Agency, Vol. 600/5-78-010, 1978.
- (268) Cahn, R.
Public Perception of Pollution Control. Proceedings of a National Symposium on Costs of Water Pollution Control, North Carolina State Univ., Raleigh, pp. 210-217, 1972.
- (269) Christensen, R. G. and C. D. Wilson.
Best Management Practices for Non-Point Source Pollution Control Seminar. U.S. Environmental Protection Agency, Vol. 905/9-76-005, November 1976.
- (270) Christenson, J. A.
People's Goals and Needs in North Carolina. North Carolina Agr. Extension Serv., North Carolina State Univ., Raleigh, December 1973.
- (271) Coughlin, R. E.
The Perception and Valuation of Water Quality: A Review of Research, Methods and Findings. Regional Science Research Institute, Discussion Paper Series 80, Philadelphia, Pa., 1975.
- (272) Dornbusch, D. M. and S. M. Barranger.
Benefit of Water Pollution Control on Property Values. U.S. Environmental Protection Agency, Vol. 600/5-73-005, 1973.
- (273) Frankel, M. L.
National Profile of Section 208 Areawide Management Planning Agencies. U.S. Environmental Protection Agency, July 1975.
- (274) Greiner, W. H.
"Iowa's Experience with a Mandatory Sediment Control Law," Journal of Soil and Water Conservation. Vol. 30(3):132-134, 1975.
- (275) Heintz, H. J., Jr., A. Hershaft, and G. C. Horak.
National Damages of Air and Water Pollution. Enviro Control, Inc., under contract to the U.S. Environmental Protection Agency, 1976.
- (276) Morris, R. L. and L. G. Johnson.
"Agricultural Runoff as a Source of Halomethanes in Drinking Water," Journal of the American Water Works Association. Vol. 68(9):492-494, 1976.

- (277) Seitz, W. D. (ed.).
Alternative Policies for Control of Nonpoint Sources of Water Pollution from Agriculture. Univ. of Illinois at Urbana. Sponsored by Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Ga., 1978.
- (278) Selig, E. I., E. Endicott, A. S. Miller, H. S. Atherton III, and M. P. Schamis.
Legal and Institutional Approaches to Water Quality Management Planning and Implementation. Environmental Law Institute, Washington, D.C., March 1977.
- (279) Train, R. E.
"EPA and Agriculture," Journal of Soil and Water Conservation. Vol. 30: 33-35, 1975.
- (280) U.S. Environmental Protection Agency.
Clean Water and the Land: Local Government's Role. January 1977.
- (281) _____.
Financial Arrangements for Water Quality Management Planning. October 1976.
- (282) _____.
Compilation of Federal, State, and Local Laws Controlling Nonpoint Pollutants. Office of Water and Hazardous Materials, U.S. Environmental Protection Agency, Vol. 440/9-75-011, September 1975.
- (283) _____.
Management Agencies Handbook for Section 208 Areawide Waste Treatment Management. September 1975.
- (284) Walker, W. R. and W. E. Cox.
Water Resources Administration in Virginia: Analysis and Evaluation. Water Resources Res. Center, Bull. 107, December 1976.
- (285) Walsh, R. G., D. A. Greenly, R. A. Young, J. R. McKean, and A. A. Prato.
Option Values, Preservation Values, and Recreational Benefits of Improved Water Quality. A Case Study of the South Platte River Basin, Colorado. U.S. Environmental Protection Agency, Vol. 600/5-78-001, 1978.
- (286) Zison, S. W., K. F. Haven, and W. B. Mills.
Water Quality Assessment--A Screening Method for Nondesignated 208 Areas. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Ga., August 1977.

OTHER BIBLIOGRAPHIES

- (287) Grimsrud, G., E. J. Finnemore, and H. J. Owen.
Evaluation of Water Quality Models: A Management Guide for Planners.
U.S. Environmental Protection Agency, July 1976.
- (288) Lance, J. C.
A Pollution Research Bibliography 1970-1976. U.S. Dept. of Agr., Agr.
Res. Serv., 1977.
- (289) Miner, J. R.
"Livestock Wastes," Journal of Water Pollution Control Federation. Vol.
43(6):991-998, 1971.
- (290) Ramsey, R. J., M. L. Rowe, and L. Merryman.
Livestock and the Environment: A Bibliography with Abstracts, Volume
II. Available from National Technical Information Service, PB-242-545,
Springfield, Va., April 1975.
- (291) Tennessee Valley Authority.
Effects of Fertilizers on Water Quality. National Fertilizer Develop-
ment Center, 1969.
- (292) Todd, D. K. and D. E. O. McNulty.
Polluted Groundwater: A Review of the Significant Literature. Water In-
formation Center, Inc., Huntington, N.Y., 1975.
- (293) U.S. Dept. Agr., Agr. Res. Serv.
A Pollution Research Bibliography 1970-1976. Washington, D.C., 1977.
- (294) U.S. Environmental Protection Agency.
Annotated Bibliography for Water Quality Management. Washington, D.C.,
May 1977.
- (295) Water Resources Scientific Information Center.
Agricultural Runoff--A Bibliography. Available from National Technical
Information Service, PB-207-514, Springfield, Va., January 1972.
- (296) Water Resources Scientific Information Center.
Irrigation Return Flow--A Bibliography. Available from National Techni-
cal Information Service, PB-249-585, Springfield, Va., December 1975.

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C. 20250

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF
AGRICULTURE
AGR 101

THIRD CLASS

